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PHYSICAL GEOGRAPHY OF THE PLEISTOCENE WITH SPECIAL REFERENCE TO PLEISTOCENE CONDITIONS

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XIV[1]

The character of the changes which marked the transition from the Tertiary to the Quaternary were somewhat unusual, though not unique as they were once believed to be. Great as these changes were, they were probably not equal in magnitude or importance to the changes which marked the transition from one great era of the earth's history to another. The significant changes at the close of the Tertiary are those which had to do (1) with the height and extent of the land and, perhaps as a result of these changes, (2) with profound alterations of climate, bringing on (3) glaciation on an extensive scale, and causing (4) migrations and mutations of life.

I. THE PHYSIOGRAPHIC CHANGES

The changes in altitude which affected the North American continent late in the Tertiary have not, in most places, been worked out in such detail as to lead to numerical results in which implicit confidence can be placed; but the general tenor of the evidence is harmonious, and the main conclusions are probably correct in their general terms. They may be summarized briefly as follows:

[1] Professor H. F. Osborn's article on "Environment and Relations of the Tertiary Mammalia," No. XIII of this series, will appear in a later number of the *Journal.*

1. In the eastern part of the continent, the land is generally thought to have stood higher than before by some few hundred feet. If the more extreme views of a few of the geologists who have studied this question are accepted, the excess of elevation over the present was a few thousand feet.

2. In the larger part of the Mississippi basin, the gain in altitude was considerable, though still on a relatively moderate scale. In the eastern and central parts of the basin it is probably to be measured by a few hundreds of feet, rather than by figures of a larger denomination. There is some reason for thinking that the important topographic features of the central Mississippi basin are chiefly of late Tertiary and post-Tertiary origin, developed from a late Tertiary peneplain now represented by the summits of the higher hills and uplands of the region, a few hundred feet above the general level in which the present valleys are sunk. It is true that these summits have sometimes been interpreted as remnants of a Cretaceous peneplain; but this conclusion is not firmly established, and the alternative suggested above is entitled to consideration.

3. In the west, the relative uplift in the closing stages of the Tertiary and early Pleistocene was greater. The estimates of the late Tertiary and post-Tertiary uplift here at one point and another range from several hundred feet to several thousand. The figures are most definite and perhaps most satisfactory near the Pacific coast. In southern California, the uplift at this time has been estimated at 1,500 feet; in northern California, 1,500 to 2,000 feet; and in the Sierras at 3,000 to 6,000 feet. In Oregon, Pleistocene marine fossils are found up to elevations of 1,500 feet, while in and about the Cascade Mountains of Washington, an elevation of several thousand feet, maximum, seems to be well established.

In British Columbia, the relative upwarp of the corresponding time has been thought to reach an amount comparable to that of the Cascade Range, while, farther north, most of the estimates point to less extensive changes. The old peneplain which is now at an elevation of 6,000 to 9,000 feet in Washington and British Columbia, is thought to descend to 4,000 or 5,000 feet far to the north. While the age of the deformation which brought the former peneplain of these northern lands to its present position has not been fixed with

precision, the best opinion seems to place it, or at least its initiation, in the late Pliocene and early Pleistocene.

Students of the western interior have reached no general agreement as to the amount of late Tertiary and Quaternary change of level, but there is general agreement that the land of that region was notably higher at the close of the Tertiary, and later, than it had been before. The increase in the height of the land amounted, perhaps, to a few thousand feet in some places, but was probably far from uniform.

4. In the West Indies and Central America, the interpretation of facts and supposed facts seems to be more or less uncertain. Spencer would make the amount of change of level in the West Indies within this general period very great, even 8,000 to 11,000 feet higher than now. Hill would have some portions of Cuba at least 2,000 feet higher than now at or since the close of the Tertiary, and the Barbadoes 1,100 feet higher at about the same time, while Hershey thinks the Isthmus of Panama has been bowed up 1,000 feet or so since the beginning of the Pleistocene.

If even the more moderate of these figures are correct, it appears that the average relative increase in the altitude of the continent must have amounted to several hundred feet at least. This amount of elevation must have been adequate (1) to increase erosion by streams greatly, this increase resulting both from (*a*) increase in precipitation, and (*b*) increase in gradient of the streams; (2) to lower in some slight measure at least the average temperature of the land, and to increase its range; and (3) to reduce the amount of vegetation on the average, both because of (*a*) the unfavorable change in temperature and (*b*) the more rapid erosion.

Outside of North America, similar changes seem to have been in progress. Thus in South America, such determinations as are at hand point to an elevation approaching 3,000 feet at a maximum on the west coast of South America, since the late Tertiary. Changes of similar import, and perhaps of comparable extent, are indicated by the facts reported from other continents, though for all but Europe, the facts are meager. In Europe, changes of level at the close of the Tertiary were not everywhere great, but about the borders of the Alps, the increase of elevation is estimated by Penck and Brückner to have been 300 to 500 meters.

It should be noted that the deformations of this time were more important in affecting the height of the land than in affecting its area. Yet from the evidence of existing floras and faunas, it seems probable that the up-swelling of the contiguous parts of America and Asia were sufficient to connect them by way of the Aleutian Islands. Shaler and Spencer have urged reasons for thinking that Florida and Cuba were connected in the late Pliocene or early Pleistocene, but this conclusion cannot be said to be established. In Europe, within the same general period of time, England has probably been joined to the continent, and southern Europe to Africa. Submerged valleys on the northwestern coast of Europe, if interpreted in the usual way, indicate elevations several hundred to a few thousand feet greater than those of the present, enough, if some of the estimates are correct, to have connected Europe with Greenland and North America. If such a connection existed, it must have entailed changes in oceanic circulation sufficient to have affected the climates of high latitudes in an important way.

The very considerable changes at the beginning of the Quaternary were followed by a great succession of changes as the period progressed. Some of them reinforced the changes just sketched, and some of them were of the opposite phase. Oscillations of level during the Quaternary have been more carefully worked out along the coast of northern Europe than in America. Unexpectedly enough, evidence seems to point to greater depression during the glacial epochs than during the interglacial. The amount of the determined oscillations of level during the Quaternary range from a few feet to a few hundred feet.

II. EFFECTS OF PHYSIOGRAPHIC CHANGES ON CLIMATE

In many parts of the earth, as in the interior and eastern part of North America, in Europe, and elsewhere, the increase of elevation at the end of the Tertiary was probably not sufficient to be of great importance climatically, in a direct way. In other regions, as in the western part of North America, on the other hand, the gain in height was probably sufficient to produce considerable effects directly.

In an indirect way, the effect of the increase of average altitude of land on climate may have been much more considerable. Erosion

was stimulated by the increase of altitude and by the decrease of vegetation due to the causes already mentioned. The increased rate of erosion led to the removal of the residual earths and alluvium which may well have accumulated on the surface to very considerable thickness, and the removal of these materials from the surface exposed the underlying rock to decay.

If changes in the constitution of the atmosphere are to be regarded as the cause, or as even one cause of climatic change, the increase of erosion at the close of the Tertiary would have led to an increased consumption of carbon dioxide, and so may have been responsible for the initial step in the series of changes which brought on the glacial climate. Though it is, perhaps, too early to affirm that the increased altitude of the land at this time was the basal cause which led to the cold climate which followed, this is a hypothesis toward which students of glacial geology are looking with much hope.

If the increased height of the land led to increased erosion, and so to increased consumption of carbon dioxide, the reduction of the amount of this gas in the atmosphere would have lowered the temperature everywhere. The resulting decrease in the temperature of the sea would have led to an increased solution of carbon dioxide from the atmosphere, thus depleting the atmospheric supply still further, and this, in turn, reacted upon the temperature and became a cause of its further reduction. This cause, therefore, once in operation, must have continued with increased effectiveness until the decay of rock was checked by decrease of altitude or temperature, or by the accumulation of ice-sheets which protected the rock beneath from ready carbonation.

III. THE DIRECT IMPORTANCE OF THE ICE-SHEETS THEMSELVES

Irrespective of the cause of the glacial climate, the covering of six million or more square miles of land in the northern hemisphere with ice hundreds and thousands of feet in thickness was in itself an extraordinary event which might well serve as an important landmark in geologic history. The ice-sheets, and especially the remarkable successions of ice-sheets, might appropriately be emphasized as proof of one of the most remarkable climatic incidents in the history of the earth, so far as now known. But apart from its great climatic signifi-

cance, each ice-sheet meant the relatively rapid superposition upon the northern continents, over the great areas indicated, of a new layer of rock, the ice, which for tracts of millions of square miles must have had a thickness exceeding a thousand feet, and perhaps a thickness of several thousand feet. The aggregate volume of this new rock, superposed on the northern parts of the northern continents, was such that it could only have been measured in terms of millions of cubic miles. The withdrawal of its substance from the sea effected a corresponding lowering of its surface, an appropriate extension of land, and an increase in its height above the sea.

Though this great body of rock new-laid upon the lands was temporary in its character, primarily because of the low temperature at which its substance assumed the liquid form, it was of great importance, from a geologic point of view, in more ways than one.

1. In the first place, the loading of millions of square miles of land with such a weight must have had an appreciable effect upon crustal movements, if the doctrine of isostasy has validity, and its disappearance, under climatic conditions which developed later, must have produced movements of the same class, but of opposite phase.

2. Again, the development of the ice-sheets put a virtual stop to the processes which had been in operation over six millions of square miles of the land, and set other processes into operation in the same places. Thus the normal phases of river work were suspended, most rivers within the ice-covered area ceasing to flow altogether. The usual phases of rock weathering and decay were practically stopped over the same areas, areas which, in the aggregate, were a very considerable fraction of the surface of the land. On the other hand, a new process of erosion was substituted for the old—erosion not restricted chiefly to the removal of decayed rock.

3. The changes in erosion were hardly greater than those in sedimentation, for instead of the assortment and separation of decayed material into its several physical classes before deposition, fine sediments and coarse, largely of undecayed material, were left promiscuously commingled. Thus on a large scale and over enormous areas deposits were made which were unlike those of comparable extent at any other stage of the earth's history, unless at times when climates were similar.

4. It should be noted further that the changes in the processes of erosion and sedimentation—changes in kind as well as in rate—were not limited to the areas actually covered by the ice, or even to the areas affected by drainage from it, or by icebergs which floated out beyond its edge. Modifications of erosion and sedimentation were felt in all areas affected, directly or indirectly, by the change of climate.

The great ice-sheets, with the recurrent disturbance which they probably occasioned in the crust of the earth and the lesser changes in the surface of the ocean; with their recurrent inhibition of the usual processes of erosion and sedimentation over great areas; with their recurrent modification of these processes over other great areas beyond the ice-sheets themselves; and with their recurrent inauguration on a large scale of processes of erosion and sedimentation which were unusual, might, without consideration of further changes of an indirect character, furnish adequate bases for important time divisions. Especially is this the case since the influence of the ice-sheets must have been felt in a physical way, throughout most if not all the earth.

IV. CHANGES IN LIFE

The great changes in the physical processes, which this on-coming of the ice-sheets brought into operation, effected corresponding changes in life, and in the processes which depend on life. In the first place, the total amount of land life must have been greatly reduced. If account be taken of mountain glaciation in both hemispheres as well as of the ice-sheets, it is probably within the limits of truth to say that conditions became so far inhospitable as nearly to eliminate land life from about one-seventh of the land of the globe, and to have rendered conditions relatively inhospitable over a still larger area. The effect upon the life of the sea is less easily stated, but it also must have been great, for the average reduction of the temperature of the sea must have been considerable.

The crowding of land life off 8,000,000 square miles, more or less, must have tended to concentrate it upon the land which still remained hospitable, and to decimate or exterminate those forms which could not migrate readily. Migration must have been forced upon the sea life as well as upon that of the land, and the shifting of the zones of both must have resulted in a shifting of the sites of organic deposi-

tion, perhaps especially of the sites where limestone was made. At the same time, the rate at which it was formed, the whole earth considered, was probably much reduced.

It would seem, from the series of physical changes sketched, that very profound changes in life should have followed, but it must be confessed that, in spite of the conditions which it would seem must have been favorable for great destruction of life, and for imposing great modifications upon that which survived, statistical evidences of the changes which followed are less impressive than would have been expected. The data at hand do point to extensive migrations, but not to the exterminations and profound modifications which might have been anticipated. It seems impossible to think that the changes of climate which drove musk oxen to Kentucky and Virginia, and Arctic plants and reindeer to the lowlands of central Europe and to the Mediterranean, were without very profound biologic significance, unless the life of the earth had reached a condition of far greater stability than that of earlier times, when lesser physical changes seem to have produced greater biological changes.

One of the features of the late Tertiary land life, and especially of the floras, seems to have been the great extent to which types were mingled. This mingling of tropical or sub-tropical forms with temperate and boreal ones seems to have begun as early as the middle of the period. The oscillations of climate which marked the Pleistocene seem to have had a sifting influence upon the migratory forms, and to have forced them to special adaptations and habitats as the period progressed. This is suggested, for example, by the floras of America and Eurasia. Gray pointed out long ago that the forest flora of the eastern part of North America is more like that of Japan than like that of the western part of our own continent. In Europe, the north-south and south-north migration of the floras as ice-sheets advanced and receded was interfered with by the east-west mountain ranges and by the seas bordering Europe on the south. In eastern Asia and America, on the other hand, the back-and-forth migration of the floras was facilitated by the greater continuity of land between high and low latitudes, and in America at least, by the absence of east-west mountain ranges. In the western part of the United States, the irregular topography made repeated latitudinal migrations of the

floras more difficult than in the eastern part, though perhaps less difficult than in Europe. In eastern Asia and in eastern America, where migration was relatively easy, the forest flora is much larger than in Europe or western North America. Thus Atlantic America and Pacific Asia have each 66 genera of forest trees, while Pacific America and Europe have but 31 and 33 genera respectively, and the number of species is approximately in keeping with the number of genera.

Vulcanism has been regarded as a factor which decreased the flora in the western part of North America as compared with the eastern; but since the floras were much the same throughout the Tertiary in all northern lands, and since the climax of Cenozoic vulcanism came as early as the Miocene, the importance of this factor in impoverishing the Pleistocene life of the western part of the United States may be questioned. Furthermore, it has little or no application to Europe, where the flora was equally reduced.

The to-and-fro movements of the land faunas and floras must have introduced an elaborate series of superpositions, giving an elaborate, orderly, and unusual succession. The record of this succession has not been worked out in its completeness, and unfortunately there is little chance that it will be worked out in its fulness unless by the most persistent care. In the regions which were glaciated repeatedly, the advance of each ice-sheet destroyed, in most places, the record of the successive floras and faunas which had lived since the preceding retreat, so that, within the area glaciated, the succession of successions is hardly likely to be found in its entirety in any one place, and perhaps not in all places. Outside the area which was glaciated, especially near the borders of the regions occupied by the successive ice-sheets, there is better chance that a complete record of the biological changes may have been preserved. The peat bogs of such regions might be expected to give complete records if they had endured continuously since the time of the first glaciation; but peat bogs are themselves temporary, and it is perhaps too much to expect that complete record of the migrations of life during the successive epochs of the glacial period will ever be found at any one place.

The records, however, of the post-glacial peat bogs are such as to give some indication of the results which would probably be found

if all the migrations could be ascertained. Thus in Scandinavia and Denmark, we have a succession of post-glacial floras, the first corresponding in a general way to the present vegetation of the tundra, the second a forest vegetation dominated by the birch and poplar, the third a forest vegetation dominated by pines, the fourth, one dominated by the oak, etc., the fifth a flora similar to that of the Black Forest Mountains, indicating a temperature warmer than that of today for the same region, and finally, a southward retreat of the last flora to its present latitude. The first five members of the succession seem to correspond with the half of a normal interglacial series. If this interpretation is correct, this series of five floras would be nearly doubled with the on-coming of another glacial epoch, and this doubled series must have been repeated, substantially, several times in the course of the long succession of glacial epochs. Fragments of interglacial records have been found both in America and Europe. In a few cases they are full enough to encourage the hope that when their number is duly increased, they may be pieced together into consistent wholes. It is too much to expect that they will ever be as complete as the record of post-glacial life.

It is not now apparent just how far biologic or paleontologic data of the Pleistocene, except from their record of climatic changes, are to be significant in correlation. Aside from the mammals, changes of species have been insignificant. Even among mammals, it is not clear that the dying-out of species in one locality was contemporaneous with the disappearance of the same species in other localities. A stratigraphic basis for this interpretation would be needed before it could be accepted. So far as all other forms of life are concerned, the paleontologic record of one interglacial epoch must have been essentially identical with that of another, if the intervals were equally long and mild.

Perhaps more help in correlation may be looked for in another direction. Intercontinental migrations, it would seem, must have been virtually restricted to interglacial epochs. The times when species first appeared in a given region may therefore prove to be much more significant in correlation than the times when species died out.

Something perhaps may be hoped for in the careful study of the

records of oscillations of level, during the period; but it seems clear that different parts of the same continent have suffered minor or even considerable deformations, independently of others. If it were established that opposite sides of an ocean basin were less independent in this respect—a doctrine for which much might be said—the movements on opposite sides of an ocean basin might be a hopeful line of research; but it cannot, at the present time, be said to have led to important conclusions.

It would appear that only through a combination of stratigraphic, climatic, paleontologic, and orogenic studies, carried out in greater detail than they have yet been, can important results in the correlation of Quaternary formations be reached, between widely separated areas.